Requirements of 4G-Based Mobile Broadband on Future Transport Networks

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Abstract—Long term evolution technologies provide new standards in mobile communications regarding available bandwidth. It is expected that users of one radio cell will share more than 100 Mbit/s in future. To take advantage of the full feature set of next generation mobile networks, transport network design has to face new requirements, caused by the architectural changes of LTE technologies. Especially the newly defined X2 interface impacts on the transport network requirements. X2 enables direct communication between evolved base stations (eNBs) and thus, enforces local solutions. At the same time a tendency of locating network elements at fewer, central sites to reduce operational expenditure can be observed, in particular concerning the transport layer. This leads to the question of how the direct X2 connection of eNBs on the logical layer can be accommodated with a general centralization of transport networks. Our considerations show that for LTE, a centralized transport network is able to realize the local meshing between eNBs. However, for LTE Advanced, the standards currently discussed by the 3GPP initiative could lead to enhanced requirements on the X2 interface latency. Consequently, the implications for the network architecture have to be analyzed in more detail.

Keywords*—*backhauling, LTE Advanced, mobile network design, X2 interface.

1. Introduction

In recent years the evolution of mobile communication proceeded mainly under the influence of the 3GPP initiative (3rd Generation Partnership Project [1]). 3GPP is a consortium, or collaboration, of standardization bodies in mobile communications. An important movement is the standardization of advanced mobile communication systems, in particular of the new technologies long term evolution (LTE) and LTE advanced (LTE-A) [2]. LTE technologies set new standards in mobile communication concerning bandwidth. In future, users of one radio cell will share more than 100 Mbit/s of bandwidth. Moreover, on the countryside, where neither appropriate DSL-based technology nor fiber-to-the-home technology is available, LTE offers new possibilities to provide flexible broadband solutions. For instance, in August 2010, Deutsche Telekom turned on the first LTE node in Kyritz, which is located in a rural area approximately 100 km north east of Berlin. To take advantage of next generation mobile networks, an adjustment and optimization of basic transport layers is inevitable. It will be necessary to analyze, which influence LTE and LTE-A take on traffic in access networks and on aggregation issues. The recent developments in telecommunication networks show the growing tendency that important network elements are concentrated at few locations. The number of sites with active hardware in access networks is reduced from tens of thousands to a few hundreds, by utilizing the optical transmission technology in combination with the increasing growth of the optical fiber network.

Concerning the current universal mobile telecommunications system (UMTS) environment, there is a star-shaped network connecting tens of thousands of antenna locations with some tens of radio network controllers (RNCs). A local meshing between base stations beyond the RNC-locations is not given in this setting. Thus, the current UMTS architecture supports the objective of reducing the number of sites and to hold complex technologies at a few locations. To design efficient fixed-mobile convergent networks, we have to answer the question which impact LTE and, in particular, the future standards of LTE-A have on network design. Will it be possible to realize the requirements of the X2 interface in terms of bandwidth and latency by using today's technology concepts? Will LTE-A lead to a trend reversal in network design? Do the antenna sites have to be connected via a local mesh? Is there active transmission hardware needed at the base stations? Are there applications for passive wavelength division multiplexing (WDM) technology?

In this paper, we present existing results found in literature and summarize these findings in order to highlight research challenges given by LTE-A. Based on this investigation, we analyze whether it is possible to meet the requirements of LTE and LTE-A, and, at the same time, reduce the number of sites in telecommunication networks. In particular, we give a brief introduction into the basics of LTE and

LTE-A in Section 2. In Section 3, we describe the development of mobile communication networks throughout the last decade. Afterwards, we analyze the requirements of LTE and LTE-A in Section 4. The results indicate that the current network structure suffices to enable the performance necessary for LTE. However, regarding LTE-A, the network architecture might have to be revisited to enable all required features. We close with a brief summary in Section 5. See [3]–[7] for recent surveys on LTE-A. Moreover, see [8] for an earlier version of this paper.

2. Basics of LTE and LTE-A

LTE has been developed as a successor of the UMTS radio network. The main features of LTE are increased bandwidth, support of multiple antennas at single base stations and the focus on packet switching (IP) protocol. In LTE, the local base stations are equipped with advanced functionality that enables them to take over tasks that have been carried out by central entities in a UMTS. The renaming of Node B (NB) to evolved Node B (eNB) illustrates the advanced abilities of the base stations. For instance, in the case of a moving user terminal, an eNB carries out independently the handover of the radio connection to a neighbored base station. In UMTS, an RNC has been responsible for this task. This modification of the network structure triggers the discussion of centralized vs. decentralized network design. In LTE, the network structure is flattened by the removal of the RNCs. However, the decentralization of important features, like handovers, implies the need for decentralizing related functionalities, like security operations. In turn, this decentralization contradicts the recent development in telecommunication networks to reduce the number of sites.

Physically, an eNB is equipped with two new interfaces. The X2 interface connects neighbored eNBs directly to support mobility [2]. For instance, handovers are enabled via X2. The S1 interface establishes a backhaul connection from an eNB to the core network. Via this connection, information is send on the user plane, as well as on the control plane.

While the standardization of LTE is finished and the first LTE sites are already established within Germany, the specification of LTE-A is still under discussion. LTE-A is designed to meet the requirements of the ITU (International Telecommunication Union) declared within the International Mobile Telecommunication (IMT)-Advanced specifications. The main design criteria for LTE-A are cost per delivered bit and system scalability. Moreover, reduction of latency, consistent area performance, and energy efficiency are addressed [9]. LTE-A shall provide a set of features to meet these requirements. These features are carrier aggregation, advanced multiple input multiple output (MIMO), coordinated multipoint (CoMP), relaying, and support of heterogeneous networks, see Section 3 for details.

The traffic growth in mobile communication is pushed by an increasing number of broadband subscribers, in particular due to a rising number of new devices, like smartphones and tablets. In addition, the number of devices is supposed to increase by newly developed machine-to-machine applications that are expected to establish machine devices in large numbers. In addition, new applications, like 3D services, establish demand for low latencies and high data rates. Consequently, those trends require the evolution of the current mobile communication network towards the standards of LTE-A.

3. The Evolution of Mobile Networks

By establishing the standardization of UMTS within the Rel-99 specification, the 3GPP initiative created a basis for increased data rates and an optimal implementation of packet based transmission. Table 1 gives details on the 3GPP standardization process and lists the 3GPP releases, the time of functional freeze, and the main radio features.

Table 1
Evolution of 3GPP specifications according to [10]

Release	Functional freeze	Main radio features of the release
Rel-99	March 2000	UMTS 3.84 Mcps (W-CDMA FDD & TDD)
Rel-4	March 2001	1.28 Mcps TDD (aka TD-SCDMA)
Rel-5	June 2002	HSDPA
Rel-6	March 2005	HSUPA (E-DCH)
Rel-7	Dec 2007	HSPA+ (64QAM DL, MIMO, 16QAM UL), LTE & SAE feasibility study, EDGE evolution
Rel-8	Dec 2008	LTE work item – OFDMA air interface, SAE work item, new IP core network, 3G femtocells, dual carrier HSPA
Rel-9	Dec 2009	Multi-standard radio (MSR), dual cell HSUPA, LTE-A feasibility study, SON, LTE femtocells
Rel-10	March 2011	LTE-A (4G) work item, CoMP study, four carrier HSDPA
Rel-11	Dec 2012	CoMP, inter-band carrier aggregation, enhanced ICIC, eight carrier HSDPA

There is a long history of standardization of advanced mobile communication systems. GSM, the first global system for digital mobile communication was specified in the late eighties to early nineties. From Rel-99 up to Rel-7, 3GPP has specified the UMTS network architecture with its packet-switched domain. On the radio side, the main focus was on increasing the data rates for the end users by means of high speed packet access (HSPA) technologies, both on the down- and uplink. Rel-7 included the HSPA+ technology and an LTE and system architecture evolution (SAE) feasibility study was started. Releases Rel-8 and 9 referred to LTE and included the orthogonal frequency-division multiple access (OFDMA) air interface specification, as well as the new SAE-based network architecture. SAE tries to simplify the architecture with an all-IP approach and it supports the requirements, like higher throughput and lower latency. Furthermore, Rel-9 also included an LTE-A feasibility study. LTE-A in its first release was frozen in spring 2011 within 3GPP Rel-10. Thus, the main building blocks of LTE-A technology are fixed. Rel-11 is targeted for December 2012 and shall include enhancements with respect to CoMP transmission, inter-band carrier aggregation and enhanced inter-cell interference coordination (ICIC) mechanisms. In this context, new requirements on backhauling networks are expected.

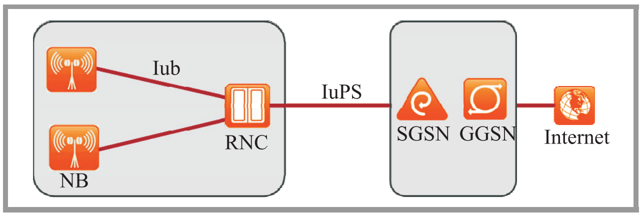

Fig. 1. 3G mobile service architecture for packet switched domain since 3GPP Rel-99 (GPRS/UMTS).

We proceed by discussing the fundamental change related to the SAE for LTE and LTE-A. Figure 1 illustrates the 3G network architecture for the packet switched domain as it has been specified by 3GPP. The NBs are connected to an RNC via an Iub interface. The RNC, e.g., takes care of the management of the NBs, the supervision of radio resources, and the handover control. The RNC is connected to the serving GPRS support node (SGSN) via an Iu packet switched (IuPS) interface. The SGSN manages subscriber access to the radio access network and it is controlling handover processes that cannot be handled by the RNC itself. Via the core network the SGSN connects to the gateway GPRS support node (GGSN). The GGSN is the mobility anchor point for the end user IP connections and implements the gateway functions towards internal service platforms and external data platforms. Therefore, it performs AAA functions, authentication, authorization and accounting, and enforces subscriber policy. The realization of a 3G network architecture is typically centralized. For instance, in the German 3G network we have tens of thousands NB sites, some tens of RNC sites, and only a fistful of GGSN sites.

The network architecture given in Fig. 1 has remained unchanged until 3GPP Rel-7. Only after specifying LTE, the basic architecture has been modified, on the one hand to increase the efficiency in mobile networks and on the other hand to meet the demand for bandwidth. Figure 2 presents the newly defined SAE architecture used for LTE. One of the major goals of the 3GPP specification of the SAE was to completely shift towards IP technology on the one hand and to flatten the network architecture on the other hand. The latter has been achieved by removing the RNC network element and distributing its functionality to the eNB, and to the mobility management entity (MME) located in the core network. As a consequence, some of the handover functionality is implemented on the eNBs, which requires in turn an exchange of information between eNBs. This issue has been addressed by defining the X2 interface, which allows direct communication between eNBs. The former SGSN and GGSN packet core nodes are architecturally replaced by the MME and the SAE-gateway (SAE-GW). In this respect, it is important to note that the MME only handles the control plane, while the user plane is directly connected from the eNB to the SAE-GW.

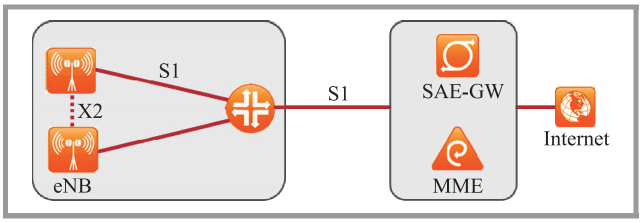

Fig. 2. 4G mobile service architecture since 3GPP Rel-8 (LTE).

We summarize the most relevant architecture differences between 4G and 3G with respect to the transport network:

- the 4G all-IP network architecture requires a packet-centric transport,
- more traffic has to be carried, since LTE and LTE-A will support up to 1 Gbit/s of traffic for a single user,
- the mobile network architecture between the eNBs and the core network sites is flat, which can also be reflected by the underlying transport network,
- X2 interfaces have been newly defined between eNBs, which needs to be covered by the transport network infrastructure.

This summary is true both for LTE and LTE-A.

The development of LTE-A focuses on providing higher bandwidths and improved performance for the users [11]. Next we consider technologies that enable LTE-A. The ITU provides clear requirements given by its IMT-Advanced (IMT-A) specifications, see Fig. 3. These requirements in-

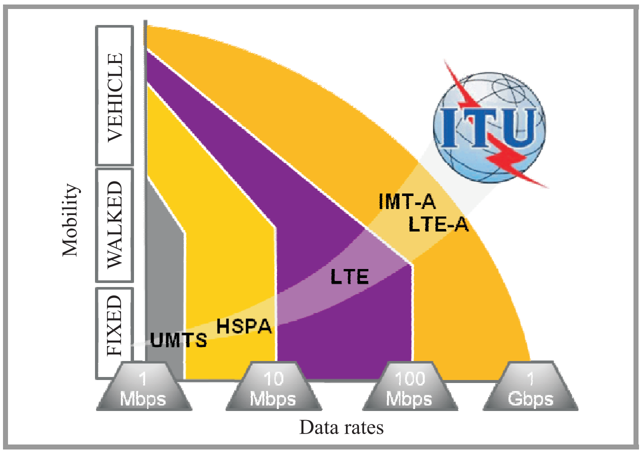

Fig. 3. LTE-A fulfills or exceeds the requirements of IMT-A defined by the ITU [2].

clude high mobility data rates of 100 Mbit/s, e.g., in trains and cars, and 1 Gbit/s for low mobility communications. The ITU requirements were taken up by 3GPP, as the basis for defining the LTE-A technology. In the mean time, the ITU has officially accepted LTE-A and IEEE 802.16m as IMT-A standards, because it was proven that these technologies can meet ITU's requirements. Figure 4 presents five approaches that enable LTE-A to achieve those high data rates.

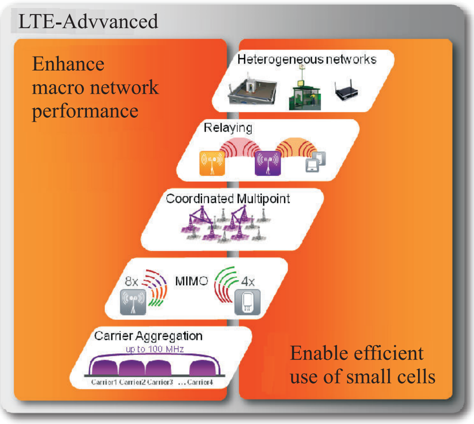

Fig. 4. Enabling technologies of LTE-A [2].

- LTE-A includes carrier aggregation of up to 100 MHz bandwidth, which is the basis in terms of frequency resources to enable very high data rates in a cell, see, [12], [13].
- Advanced MIMO antenna schemes are necessary to implement high data rates. Simulations indicate that up to eight eNB and eight user equipment antennas can be utilized efficiently [14] by MIMO.
- With CoMP it becomes possible to not only achieve better performance at the cell edges, it enables also enhanced interference cancellation mechanisms to improve the overall network performance, see, [15].
- Relaying through the radio access network avoids unnecessary investments in fiber infrastructure, especially for smaller cell diameters. This is because the available LTE spectrum can be used to transmit traffic directly between eNBs via the air interface. See [16], [17], [18] for studies on coverage extension through relaying technique.
- Heterogeneous networks will become an important matter and have to be better supported in future. Radio network deployments will include macro cells, but also micro, femto and pico cells [4], [19]. In this case overlapping of different signals at the user equipment can become a serious performance limitation. Therefore, LTE-A addresses the question how interferences can be avoided. One possibility is the coordinated elimination of interferences between eNBs, the ICIC.

4. Optimizing Transport Networks for 4G

One major aspect of transport network design for LTE is to deal with the increased bandwidth due to an increase of peak and average data rate. However, another important issue is to reduce latency. The users' quality of experience is affected not only by the data rate but also by latency. In addition, low latency is an important precondition to achieve high data rates due to throttling mechanisms of TCP/IP.

The roundtrip time can be crucial for network performance and thus affects the customers' quality of service. Not only for voice, but also for data communication a low latency, or, low roundtrip time is desirable. Figure 5 shows typical round trip times of different mobile access technologies, and, as reference, of DSL access. Note that the provided values are achievable in networks in low load condition and for a server that is located near to the radio access network. It can be observed that already with HSPA and HSPA+ technology the roundtrip time is strongly improved. However, these values are again clearly outperformed by LTE technologies. Even DSL technology can no longer compete with LTE in terms of latency, at least as long as interleaving is enabled for the sake of correcting errors. Therefore, there should be no doubt that LTE technology, providing a value of 20 ms roundtrip time is suitable for providing all kinds of real-time applications to end users.

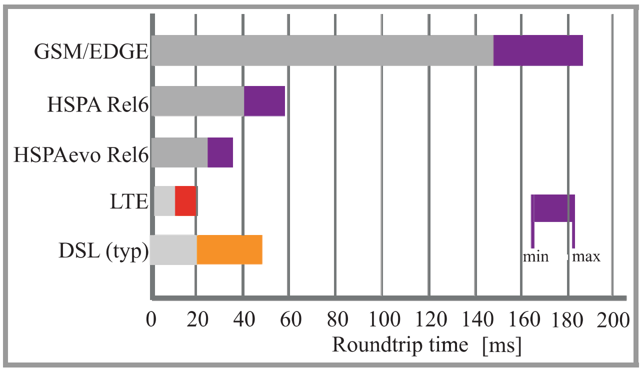

Fig. 5. Typical roundtrip times for different access technologies, server near RAN (data based on measures from Siemens, Nokia as well as [14], [20]).

We already pointed out earlier that the X2 interface, representing the logical interface between two eNBs is a very important conceptual building block of LTE, because the handover process is now controlled by the eNBs themselves. The question remains how to implement the X2 interface by means of the transport network. Before we analyze this in more details, we next provide a description of the main task of the X2 interface, namely the handover process in LTE networks. Figure 6 provides a schematic view on the handover process in LTE networks. The graphic depicts a user terminal, two eNBs and a gateway. The data streams are given as S1-u or X2-u where 'u' stands for the user

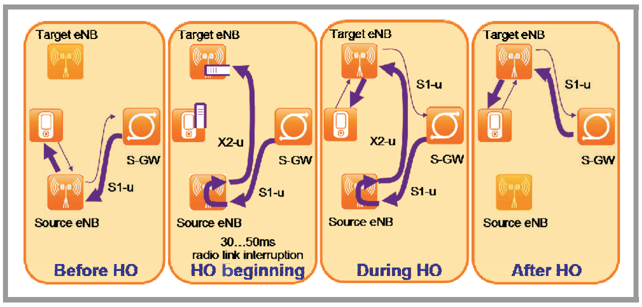

Fig. 6. Handover process in LTE networks.

plane. On the left, a situation is given where a terminal is connected to the source eNB, but is moving into the direction of another eNB. This is the starting point and denoted as the situation before the handover starts. As the terminal moves closer to the target eNB, the handover starts. For a duration of between 30 and 50 ms the radio link is interrupted as the user data is transferred via the X2 interface from the source to the target eNB. During the handover, the terminal is already connected to the target eNB via the air interface, but the target eNB still receives the user traffic via the X2 interface connected to the source eNB. Only when the handover is completed also on the MME, the SAE-GW redirects the traffic directly to the target eNB. From these observations we can conclude that it will be sufficient to have a latency of less than 30 to 50 ms on the X2 interface to maintain the service quality. This fact will be important when defining the requirements for an optimized transport network architecture for LTE.

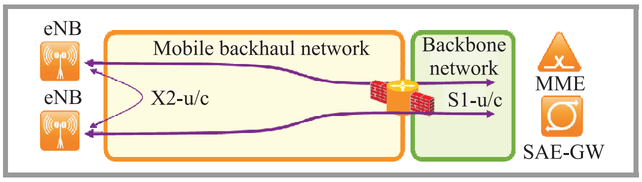

Fig. 7. Direct X2 connectivity between eNBs.

We proceed by considering backhauling in mobile networks. In general, there are two potential backhauling alternatives from a high-level point of view. These alternatives are given in Figs. 7 and 8. The notations ‘u’ and ‘c’ should indicate that we consider traffic from the user plane, as well as from the control plane. As illustrated in Fig. 7, X2 traffic can be routed directly between the eNBs. This might include packet functions in the transport network. As a consequence, we have a local meshing between the eNBs for realizing the X2 interface. As distances are short for direct X2 connectivity, we have an improved transport latency. However, to some extent, this is contradicting today’s 3G security architecture, as indicated by the firewall symbol. Typically, all traffic from and to the eNB is encrypted by means of Internet protocol security (IPSec). Today, the IPSec gateways are located centrally in the network, in order to ease operations. Thus, in the case of direct X2 connectivity, the traffic no longer passes through the central IPSec gateways. As a consequence, the security architecture would need to be adapted, too. This could be done either by decentralizing the IPSec gateways, or, by implementing a fully decentralized security architecture, where the target eNBs can decrypt traffic themselves.

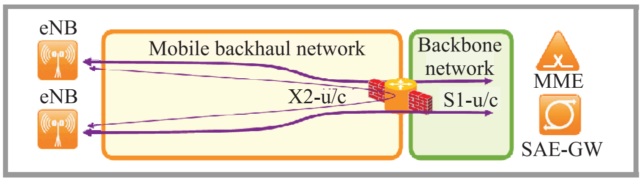

Fig. 8. Indirect X2 Connectivity Via Core Network.

Figure 8 depicts an alternative where the X2 traffic is routed via the core network and still passing through the centralized IPSec gateways. This scenario increases transport latency, but it allows to keep the current centralized security architecture. To realize this alternative, it is important to analyze whether the additional transport latency is jeopardizing the users’ quality of experience. Remember that for LTE, a roundtrip time of about 20 ms is given, see Fig. 5. On the other hand, due to the handover process, we have to deal with interruptions of the connection up to 50 ms anyway. Thus, it is fair to say that indirect X2 connectivity will not harm the quality of experience. In consequence, we can state that there is no reason and no need to implement direct X2 connectivity in case of LTE. The question remains whether this important result still holds true for LTE-A?

The specification of LTE-A is currently in an important stage [21]. New approaches have to be developed to enable 1 Gbit/s bandwidth, and at the same time, a decreased latency. Under this light, an extended usage of the X2 interface is under discussion. It is planned to design the extended X2 interface not only for the handover process, but also for information exchange in order to improve network performance. The most prominent example is the CoMP transmission where an end user terminal can receive traffic from multiple eNBs simultaneously. This approach aims to increase service quality at cell edges and to increase bandwidth.

Three CoMP-methods are under discussion:

- Coordinated scheduling / Coordinated beamforming (CS/CB),
- Joint processing / Dynamic cell selection (JP/DCS),
- Joint processing / Joint transmission (JP/JT).

Figure 9 shows, exemplary for CoMP JP/JT, how data transmission is carried out simultaneously from different eNBs. Important for the realization of CoMP is the ICIC. Some ICIC methods use the X2 interface for the exchange of information concerning interferences among the eNBs. Other methods base on a strict synchronization of eNBs, in particular if there are no X2 interfaces available in heterogeneous networks. For carrying out CoMP and ICIC, we have restrictive requirements on the transport network infrastructure, i.e., on the X2 interface bandwidth and on latencies. Simulations show very well that the lower the delay on the X2 interface, the more efficient the mechanisms work. Currently, there are latency values of about 1 ms under discussion [22].

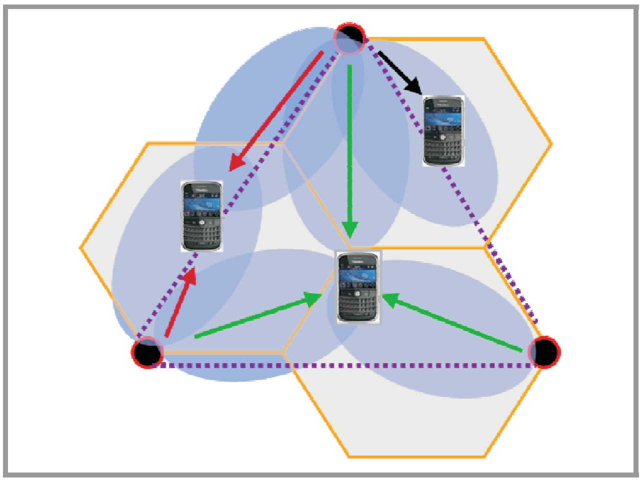

Fig. 9. Simultaneous data transmission from different eNBs to user equipment for CoMP JP/JT.

As stated before, the realization of X2 connectivity via core networks is realizable for LTE. In fact, for LTE, there is no benefit regarding latency when choosing the direct X2 connectivity. On top of that, a modified security architecture would be necessary when choosing direct X2 connections.

However, if latencies of 1 ms become standard for LTE-A, those issues will have to be reconsidered. The speed of light in the fiber provides a transport latency of 0.5 ms per 100 km. On top, processing latency has to be added for the central network element providing X2 connectivity. As a result, by rule of thumb one derives a maximum distance of 50 km between an eNB and a central network element. Thus, for implementing LTE-A, a direct X2 connectivity would become necessary, see Fig. 10. Summarizing, we could still support even very stringent latency requirements on the X2 interface by means of a direct transport connection between the eNBs. However, in this case the security architecture need to be implemented differently, as discussed previously.

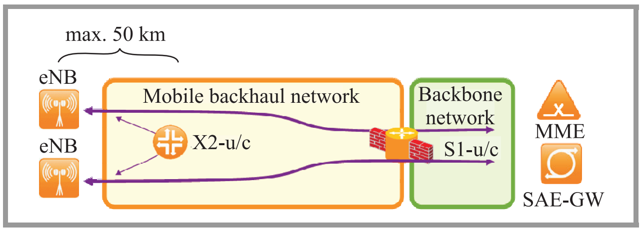

Fig. 10. CoMP may require direct X2 connectivity between eNBs due to stringent latency requirements.

Next we present an alternative approach. In today's typical deployments the NBs are located at the antenna sites. However, there are approaches of separating the more complex NB functions from their radio functions. The different functions of a base station are defined by OBSAI [23], the Open Base Station Architecture Initiative. Figure 11 shows this kind of separation of NB functions and radio functions in more details. Only the radio frequency (RF) modules of the base station are located on the antenna sites, the system modules or baseband modules are physically separated and deployed in centralized locations. Optical fiber and passive WDM technology can be deployed to transmit the OBSAI signals between RF and system modules. Such kind of separation is not only attractive from an operational perspective. This is due to the fact that more complex and error prone components of the base station can be placed centrally. Also the logical X2 interface can be implemented locally in the central locations between the system modules. It is even possible that one system module can serve multiple RF modules, so that synchronization information for CoMP is available naturally in one device.

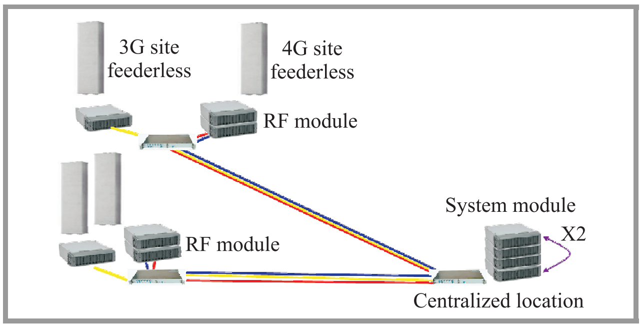

Fig. 11. Separation of RF and baseband modules.

However, this future option still requires further analysis and development. Another aspect makes the concept of functional separation interesting: if one moves towards smaller and smaller cells one might end up with femtocells, which might reside in a traffic light or a street cabinet. The reduction of size and power consumption at the antenna site will provide new flexibility in mobile network design.

5. Conclusion

LTE and LTE-A are exciting and important technologies for the future of communications. This is true not only in the case of mobility applications, but for special fixed broadband applications in the countryside, too. LTE is installed today in first locations and LTE-A is on its way regarding standardization. Technology for the user terminal, e.g., modems for the laptop or smartphones with LTE functionality is already available today. It is important to analyze the requirements of future access technologies already at an early stage, in order to optimize the underlying transport network architectures. Currently, not all requirements of LTE-A are specified, especially with respect to CoMP and the impact of the X2 interface. Our first analysis shows that the current transport network evolution strategies do not compromise any future roll-out of new broadband wireless access technologies.

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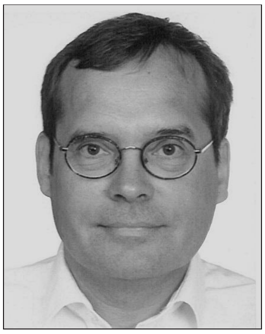

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